A SEARCH TECHNIQUE FOR WEAK AND LONG-DURATION GAMMA-RAY BURSTS FROM BACKGROUND MODEL RESIDUALS

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ABSTRACT

We report a planned search technique for Gamma-Ray Bursts too weak to trigger the on-board threshold. The technique is to search residuals from a physically based background model used for analysis of point sources by the Earth occultation method. Searching residuals (as opposed to raw data) minimizes false triggers from occultation edges and many other effects which lead to a rapid variation in the raw count rate, The background model is based on physical parameters, such as charged particle count rates and atmospheric secondaries. This allows fitting to long periods (e.g., several orbits), which in turn increases search effectiveness for bursts of longer duration. Initial results and expectations are presented.

INTRODUCTION

The Burst and Transient Source Experiment (BATSE) has provided one of the *Compton Gamma Ray Observatory's (CGRO)* most important scientific results: Gamma Ray Bursts (GRB) are isotropic but distributed inhomogeneously in space, with a deficit of weaker (more distant) bursts (Fishman et al. 1992; Meegan et al. 1992). The most recent results (Fishman 1993) essentially exclude galactic and galactic halo distributions, thereby essentially eliminating the pre- *CGRO* favored hypotheses of origin, viz., events associated with galactic neutron stars.

This paper describes a technique for an offline search of BATSE data which should extend BATSE's sensitivity to substantially weaker bursts, particularly to bursts of longer duration (say, $\gtrsim 10$ s). In this technique, the count rate is fit to a physically based model; in this manner most variations in count rate are modeled, so that bursts having a duration on the order of the orbital variations can nevertheless be detected. The value of this search will be in providing at least some insight into the spatial distribution of burst sources, and hence into the origin of GRB, provided that a sufficient number of bursts can be detected to, in effect, extend BATSE'S log N-1og S curve substantially below its onboard threshold.

METHOD

The search will be conducted on residuals from the background model used in the JPL Enhanced BATSE Occultation Package (EBOP) (Skelton et al. 1993). Use of this model is a key element of the strategy. The background model incorporates the following terms, which are illustrated in figure 1 for the 96–121 keV energy range:

- Constant *Background:* This term simply accounts for the diffuse isotropic cosmic background and slowly varying effects, such as long-term cosmic-ray activation.
- *Earth Blockage of Cosmic Diffuse Background:* This term is expected to be negative by virtue of its definition as a deficit in the diffuse background. When the BATSE Large Area Detector (LAD) is pointed away from the Earth, it remains negative instead of going to zero, probably because of LAD response at angles greater than 90 degrees. At higher energies, the magnitude of this term decreases, and the mathematical fit value can become positive; this is because the mathematical model automatically incorporates some contributions from non-local atmospheric cosmic-ray secondaries into this term. (The Earth Albedo for Cosmic Rays term, described below, accounts for cosmic-ray secondaries proportional to the local cosmic-ray flux.)

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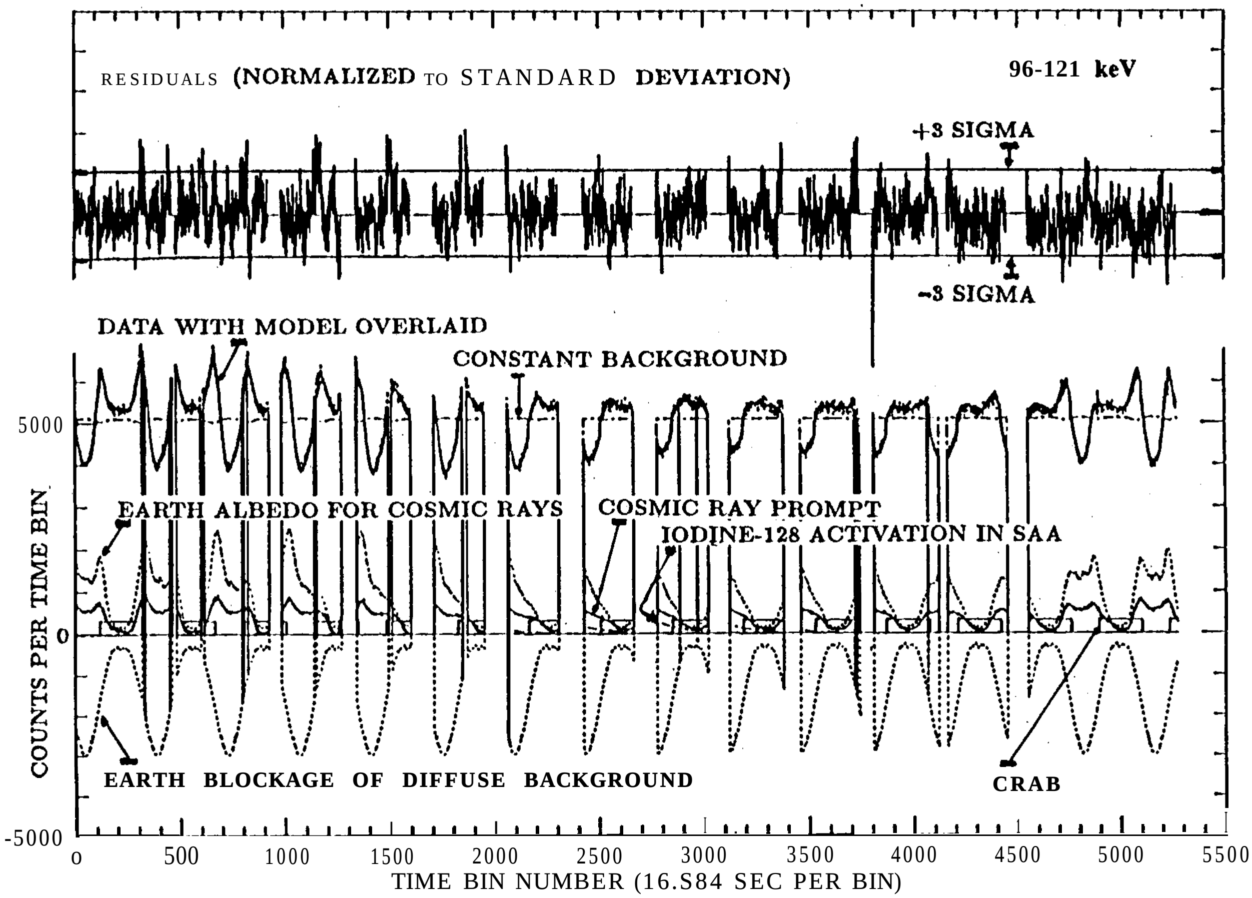

Figure 1. Buildup of components in the background model used in the EBOP.

- *Cosmic Ray Prompt:* This term primarily reflects prompt secondaries from cosmic rays striking the instrument or spacecraft but not being vetoed. The cosmic-ray rate is obtained from ULD rates of the 8 BATSE Spectroscopy Detectors.
- *Earth Albedo for* Cosmic *Rays*: This term includes factors for both the cosmic-ray rate and the Earth exposure; it reflects the major contribution of atmospheric secondaries, which is proportional to the local cosmic-ray rate.
- ^{128}*I Activation in* SAA: This term represents contributions to the count rate which decay with the 25-rein half-life of ^{128}1, A separate term is added following each South Atlantic Anomaly passage.
- Crab: This rectangular wave represents the one point source in the example of figure 1, namely the Crab nebula and pulsar. The height of the step corresponds to the-signal being extracted from the count rate.

In the upper portion residuals for each time bin (normalized to the formal statistical error) are plotted. Use of the residuals from this model, as opposed to raw data, is a crucial element in this search; this is because the raw data contain occultation edges and other periods of rapid variation which would lead to a higher false trigger rate for the same sensitivity y.

Once residuals are obtained, the burst search will consist in applying filters to them and looking for positive transients, The baseline filter shape is a boxcar with negative wings; various widths will be used. This ‘t we-sided” filter offers a significant advantage compared to the “one-sided” rising edge exceedance of a floating threshold, as implemented onboard. In order to become a burst candidate, a transient would need to be confirmed by at least 2 LADs, would” need to come from unocculted space, would not correlate with known solar flares, and would display consistent temporal behavior among the LADs detecting it. The onboard trigger is somewhat anisotropic (Brock et al. 1992) owing to the fact that

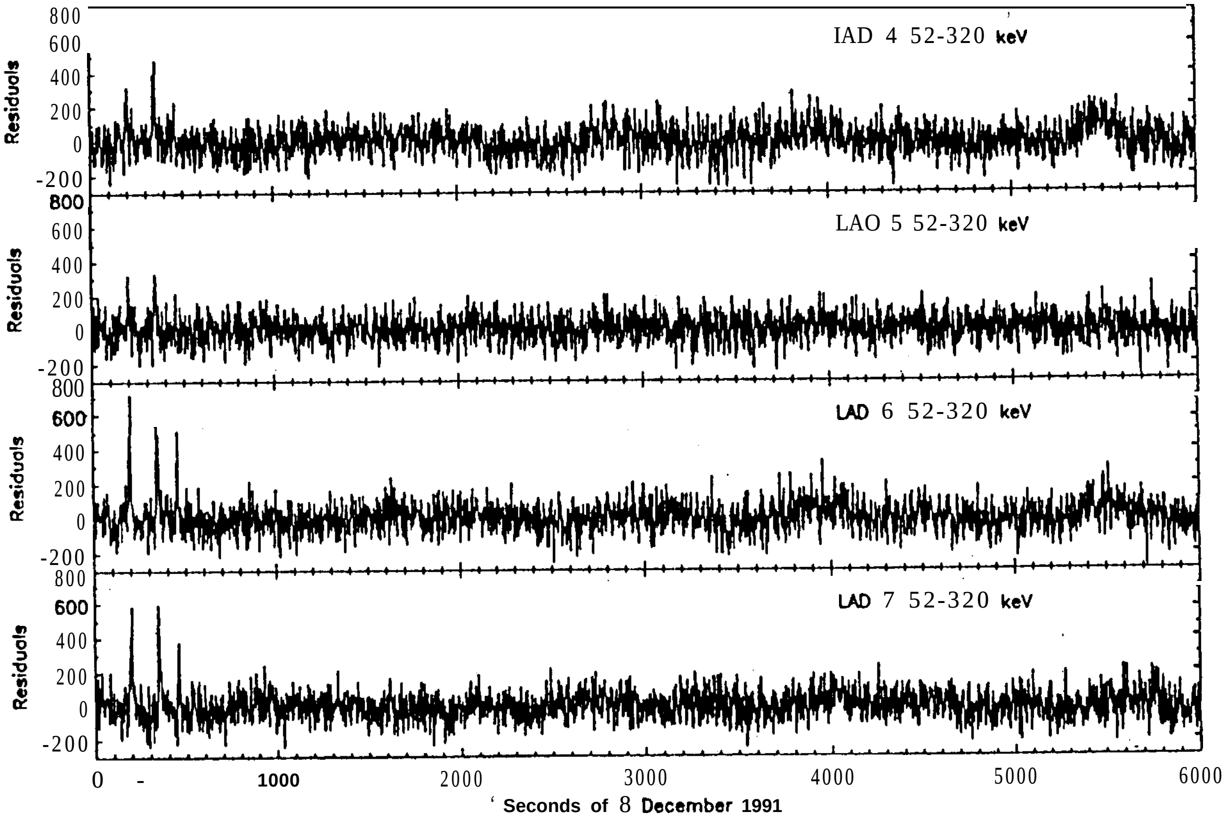

Figure 2. EBOP background model residuals for the first 6000s of 8 December 1991. A known gamma-ray burst, BATSE trigger #1152, marginally detected onboard, is clearly visible as the series of three pulses within the first 500 s.

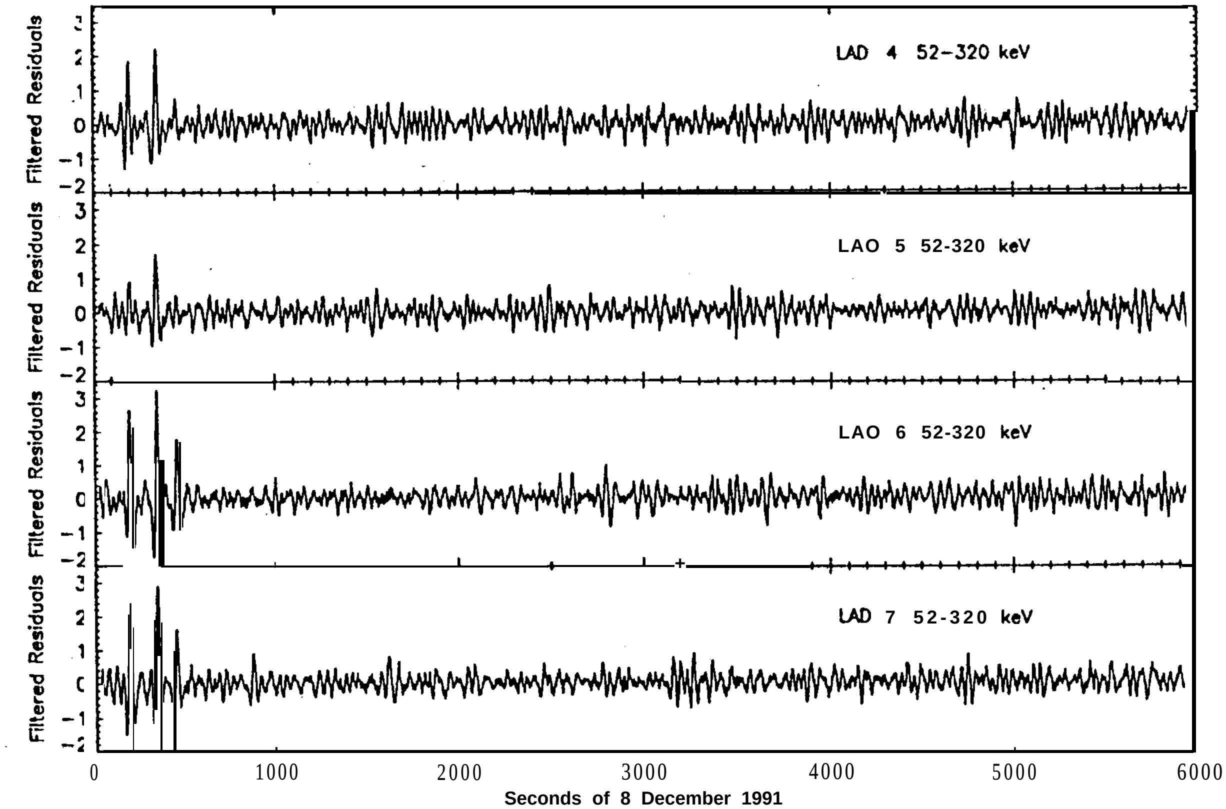

Figure 3. The residuals from figure 2, above, after convolution with a boxcar filter of 16 s width. This value closely matches the width of the pulses in this particular burst.

the required second LAD may present a cosine ranging from 0.333 to 0.816 to the burst direction. In cases when the second LAD has a smaller cosine, the third (and even fourth) LAD can have a cosine near that of the second. Consideration will be given to mitigating the anisotropy by allowing multiplicity (third or fourth LAD) to generate a candidate with less threshold exceedance in the second LAD. Since false alarms in the onboard trigger impact the instrument, it is obvious that an offline search can tolerate a higher false alarm rate.

EXAMPLE

Figure 2 shows the potential of this method. Shown are the residuals for LADs 4 through 7 for the first 6000 seconds of 8 December 1991. This period includes a known burst, BATSE trigger #1 152. This burst came in three pulses, at 200 s, 340 s, and 460 s; the BATSE trigger was on the middle one, with a threshold exceedance factor of 1.007, which is to say that it was barely detected.

Figure 3 shows the residuals after being filtered by a 16-s square-wave filter of zero net area. Such a filter accentuates features matching its width. This burst is detectable at 9.3 σ in the unfiltered residuals and 13 σ after filtering, where the o-levels refer to the second-strongest LAD. It is clear that this burst stands out clearly above any other features in the period shown.

SCOPE OF CURRENT AND FOLLOW-ON EFFORT

The current effort is scoped to adapt the existing background model to the burst search and to search 100 days of BATSE CONT (2-second, 16 energy channels) data. These data are already at JPL in connection with the Earth Occultation program. Tasks include development of the software to interface between the Earth occultation model to the burst search, development of the burst search software to examine the data on various time scales, and examine energy band selection options, timing options, and threshold selection. Should the pilot effort achieve a significant increase in sensitivity, a follow-on effort would involve continued analysis and possible extension of the technique in cooperation with the BATSE PI team.

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